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SENSITIVITY OF AIRCRAFT RUNUP/COMMUNITY NOISE PREDICTIONS TO EXCESS GROUND ATTENUATION

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AEROSPACE MEDICAL RESEARCH LABORATORY
AEROSPACE MEDICAL DIVISION
AIR FORCE SYSTEMS COMMAND
WRIGHT-PATTERSON AIR FORCE BASE, OHIO

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The experiments reported herein were conducted according to the "Guide for the Care and Use of Laboratory Animals," Institute of Laboratory Animal Resources, National Research Council.

The voluntary informed consent of the subjects used in this research was obtained as required by Air Force Regulation 80-33.

This report has been reviewed by the Information Office (OI) and is releasable to the National Technical Information Service (NTIS). At NTIS, it will be available to the general public, including foreign nations.

This technical report has been reviewed and is approved for publication.

FOR THE COMMANDER

Henning E. von Gierke

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Director
Biodynamics and Bioengineering Division
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This study examines the sensitivity of aircraft ground runup noise predictions to the accuracy of excess ground attenuation algorithm presently used in NOISEMAP. Day/Night Level (DNL) noise exposure contours were computed for one hour of single engine military power ground runup activity by F-4, C-131, and C-5 aircraft. These aircraft were chosen since they have straight jet, low bypass ratio fan, and high bypass ratio fan engines,

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The propagation algorithms studied were: no excess ground attenuation, standard NOISEMAP excess attenuation, and NOISEMAP excess attenuation plus and minus one standard deviation of the field test data used to develop the present NOISEMAP algorithm.

The results showed DNL 65 area changes of approximately ± 40 percent for the straight jet, ± 30 percent for the low bypass ratio fan jet, and up to 10 percent for the high bypass ratio fan jet due to ± one standard deviation changes in the attenuation algorithm. Assuming no excess ground attenuation, the results showed the DNL 65 area increased approximately 100% for both the F-4 and C-141 type engines and 4% for the C-5 type engines.

This study clearly substantiates the need for further field measurements planned by AMRL in 1977 and 1978 to refine or modify the ground propagation algorithm and establish confidence in its accuracy.

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SUMMARY

As noise propagates over the ground, the sound level decreases with distance from the source. This reduction is due to phenomena such as divergence of the sound waves, absorption of the sound energy by the atmosphere, and interaction with the ground cover. The losses due to ground effects are called excess ground attenuation.

The field data used to develop the excess ground attenuation algorithm presently in NOISEMAP show considerable scatter. These uncertainties impact the ability of NOISEMAP to predict with confidence the noise exposure from ground runup operations. This study examines the sensitivity of ground runup noise predictions to the accuracy of the excess ground attenuation algorithm used in NOISEMAP.

Day/Night Level (DNL) noise exposure contours were forecast for three types of military aircraft engines using four variations of the excess ground attenuation algorithm. One hour of single engine military power ground runup activity was assumed for the F-4, C-141, and C-5 aircraft. These aircraft were chosen because they have straight jet engines, low bypass ratio fan engines, and high bypass ratio fan engines, respectively, having considerably different noise spectra. A-weighted sound level versus distance curves were developed for each aircraft for each ground propagation algorithm. These curves were computed as a function of angle since the spectral characteristics of runup noise vary around the aircraft. The propagation algorithms studied were: no excess ground attenuation, standard NOISEMAP excess attenuation, and NOISEMAP excess attenuation plus and minus one standard deviation of the field test data used to develop the NOISEMAP algorithm.

The results showed DNL 65 area changes of approximately ± 40 percent for the straight jet, ± 30 percent for the low bypass ratio fan jet, and up to 10 percent for the high bypass ratio fan jet due to ± one standard deviation changes in the attenuation algorithm. Assuming no excess ground attenuation, the results showed the DNL 65 area increased approximately 100% for the F-4 and C-141 type engines and 4% for the C-5 type engines.

This study clearly substantiates the need for further field measurements planned by AMRL in 1977 and 1978 to refine or modify the excess ground attenuation algorithm and reduce, if possible, the uncertainties associated with the algorithm presently used in NOISEMAP.

PREFACE

This report is one of a series describing the contractual and in-house research program undertaken by the Aerospace Medical Research Laboratory under Project/Task 723104, Measurement and Prediction of Noise Environments of Air Force Operations, to develop a procedure for predicting the community noise exposure resulting from aircraft operations. Other reports previously published under this research program include: AMRL-TR-73-105, "Community Noise Exposure Resulting From Aircraft Operations: Application Guide for Predictive Procedure"; AMRL-TR-73-106, "Community Noise Exposure Resulting From Aircraft Operations: Technical Review"; AMRL-TR-73-107, "Community Noise Exposure Resulting From Aircraft Operations: Acquisition and Analysis of Aircraft Noise and Performance Data"; AMRL-TR-73-108, "Community Noise Exposure Resulting From Aircraft Operations: Computer Program Operator's Manual"; AMRL-TR-73-109, "Community Noise Exposure Resulting From Aircraft Operations: Computer Program Description"; AMRL-TR-73-108, Appendix "Community Noise Exposure Resulting From Aircraft Operations: NOISEMAP Program Operator's Manual"; AMRL-TR-73-108, "Addendum For Version 3.3 of NOISEMAP"; AMRL-TR-75-115, "Sensitivity Studies of Community-Aircraft Noise Exposure (NOISEMAP) Prediction Procedure"; AMRL-TR-76-111, "Validation of Aircraft Noise Exposure Prediction Procedure"; AMRL-TR-76-115. "Aircraft Sideline Noise"; AMRL-TR-76-116, "Further Sensitivity Studies of Community-Aircraft Noise Exposure (NOISEMAP) Prediction Procedure"; AMRL-TR-76-123, "Calculation of Sideline Noise Levels During Takeoff Roll"; and AMRL-TR-76-124, "Selection of Minimum Day/Night Levels for NOISEMAP Contour Calculations". Technical monitor for this effort was Mr. Jerry Speakman of the Biodynamic Environment Branch.

SENSITIVITY OF AIRCRAFT RUNUP/COMMUNITY NOISE PREDICTIONS TO EXCESS GROUND ATTENUATION

I. INTRODUCTION

This study examines the sensitivity of ground runup noise predictions to the accuracy of the excess ground attenuation algorithm. First, excess ground attenuation will be defined and the general nature of the problem will be presented. Then the procedure used to analyze the problem will be outlined and the conclusions summarized.

II. EXCESS GROUND ATTENUATION

As noise propagates over the ground from a source to a listener, the sound level diminishes with distance traveled. This reduction is caused by phenomena such as divergence of the sound waves, absorption of sound energy by the atmosphere and interaction between the sound waves and the ground.

The losses due to ground effects have been termed excess ground attenuation (EGA). Schemes to predict these losses have been developed and are referred to in this report as ground attenuation algorithms.

Several such algorithms have been proposed[1,2] and one of these is currently used by the Air Force in their land use planning activities. However, the field data used to develop this algorithm show considerable scatter. Consequently, there has been a lingering question as to the accuracy of the algorithm and the impact of possible inaccuracies on noise predictions. Several studies have been proposed to measure excess ground attenuation more accurately in the field and refine the existing ground propagation algorithms.

This study, performed in support of the field measurement programs, investigates the sensitivity of noise predictions to the accuracy of the algorithm. In other words, if we change our current propagation model, will there be an appreciable change in the noise predictions rendered?

The general impact of incorporating excess ground attenuation into sound propagation calculations is illustrated in Figure 1. This figure shows the frequency spectra resulting from an F-4 runup at both 3200 feet and 8000 feet. Spectra are presented that assume no excess attenuation as well as assuming the standard attenuation. These curves clearly show that for this algorithm EGA is most important at large distances and low frequencies.

III. PROCEDURE

To evaluate the sensitivity of noise predictions to the accuracy of the ground propagation algorithm, a simple approach was taken. Day-night level (DNL) exposure areas were forecast for three military jet aircraft using four variations of the excess ground attenuation algorithm. The four exposure predictions for each aircraft were then compared to see if changing the ground attenuation algorithm caused substantial changes in the predicted noise exposure.

The measure used to assess the effect of the runup propagation algorithm was the calculated area within a defined DNL contour or equivalently, the area where the sound exposure is greater than a defined level. For this study, one hour of military power operation was assumed for each aircraft. This duration was chosen since it is representative of daily runup times that actually occur.

The three aircraft chosen were the F-4, the C-141 and the C-5. These aircraft were chosen because they have straight jet engines, low bypass ratio fan engines and high bypass ratio engines, respectively. Each of these engine types has a different frequency spectrum as shown in Figure 2. Since ground attenuation is a frequency dependent phenomenon, it is important to investigate several sound sources having different spectra.

The first step in calculating exposure areas was to develop A-weighted sound level versus distance curves for each of four ground propagation algorithms, for each aircraft. These level versus distance curves were calculated for a range of angles around the aircraft since the spectral characteristics of runup noise vary around the aircraft. Spectra were developed for the following ground propagation algorithms.

1. Standard air-to-ground propagation, with no excess ground attenuation.

2. Standard excess ground attenuation. This standard attenuation is that currently used by the Air Force's OMEGA 6.6 computer program.

3. Standard excess attenuation minus a frequency dependent factor, σ.

4. Standard excess attenuation plus σ additional attenuation.

The standard ground attenuation is shown in Figure 3 and the minus and plus σ attenuation algorithms are shown in Figures 4 and 5, respectively. The values of σ were chosen to represent the standard deviation of the test data used to develop the

standard ground algorithm. The plus and minus σ algorithms represent the range of the possible algorithms that might have been derived from the original field data.

The noise level versus distance data for the three test aircraft, for each of the four propagation algorithms are tabulated in Appendix A. Figure 6 shows the A-level versus distance curves for the F-4 at 140 degrees. This figure is presented to show graphically the general effect of the different algorithms on the A-weighted sound level.

After calculating the noise versus distance profiles, the next step was to use these profiles to calculate the exposure areas. The NOISEMAP computer program was used to calculate these areas with the results given in Table 1. Also shown in this table are the area changes that result from using the "plus σ" or "minus σ" curves instead of the standard curve. These area changes are expressed as a percentage of the standard area. The "no excess attenuation" areas are presented to show the importance of the ground attenuation relative to standard air-to-ground propagation.

IV. RESULTS

Table 1 indicates that a deviation of ±σ from the standard ground attenuation curve would result in an area change of about ±40 percent for the F-4, ±30 percent for the C-141 and from 1 to 10 percent for the C-5.

The percent area change is a function of the frequency spectrum of the noise source and of the distance from the source to the contour being examined. If a noise source has no frequency components below 800 Hz, or if the contour of interest is less

than 1,000 feet from the source, then the predicted area within the contour will be unaffected by the details of the ground propagation algorithm. The contour area is most sensitive to the details of the ground propagation algorithm when the sound source produces significant sound energy below 800 Hz and is loud enough to cause significant DNL values at distances greater than 6,000 feet from the source. Thus, the sensitivity of noise prediction, as measured by the size of specific noise contours, is dependent on both source level and source spectral characteristics.

Since the F-4 has the highest sound levels of the three aircraft examined, and also has a good portion of its energy in the low frequency bands, excess attenuation should have a greater impact on the size of its 65 DNL contour than the 65 contour for other aircraft. This was born out by calculations.

Figures 3 through 5 show that the EGA is most important for sound sources with substantial low frequency (below about 300 Hz) energy. Since the F-4 is a straight jet, it produces more low frequency energy than the other aircraft and its radiated noise levels are more sensitive to the EGA algorithm than the C-141 or C-5. In fact, the C-5 has so little energy in the low frequency bands that ground attenuation has little impact on the predicted exposure area.

Figure 7 shows the 65, 75 and 85 DNL contours for the F-4 that result when each of the four EGA algorithms is applied. It can be seen from this figure that the position of the contours is most sensitive to the EGA algorithm at angles of maximum noise energy. This occurs because noise at the maximum energy angle typically has the most low frequency noise energy.

V. CONCLUSIONS

Since turbojet aircraft produce high noise levels containing significant low frequency energy, excess ground attenuation should be modeled accurately in order to obtain good noise predictions for these aircraft at large distances. However, due to the scatter in the field data used to develop the ground propagation model, the current prediction method could be calculating exposure areas that are in error by as much as forty percent at distances greater than 6,000 feet. Moreover, reducing this potential error due to scatter does not eliminate other possible inaccuracies in the model that may have been introduced by other limitations of the original measurements such as the absence of upwind attenuation observations.

The combination of uncertainty in the model due to scatter as well as the lack of data for a variety of measurement conditions clearly substantiates the need for further field measurements to refine or modify the ground propagation algorithm and establish confidence in its accuracy.

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1. Franken, Peter A., and Bishop, Dwight E., "The Propagation of Sound from Aircraft Ground Operations", NASA CR-767, 1967.

2. SAE Research Committee R2.5, "Technique for Developing Noise Exposure Forecasts", FAA DS-67-14, August 1967.

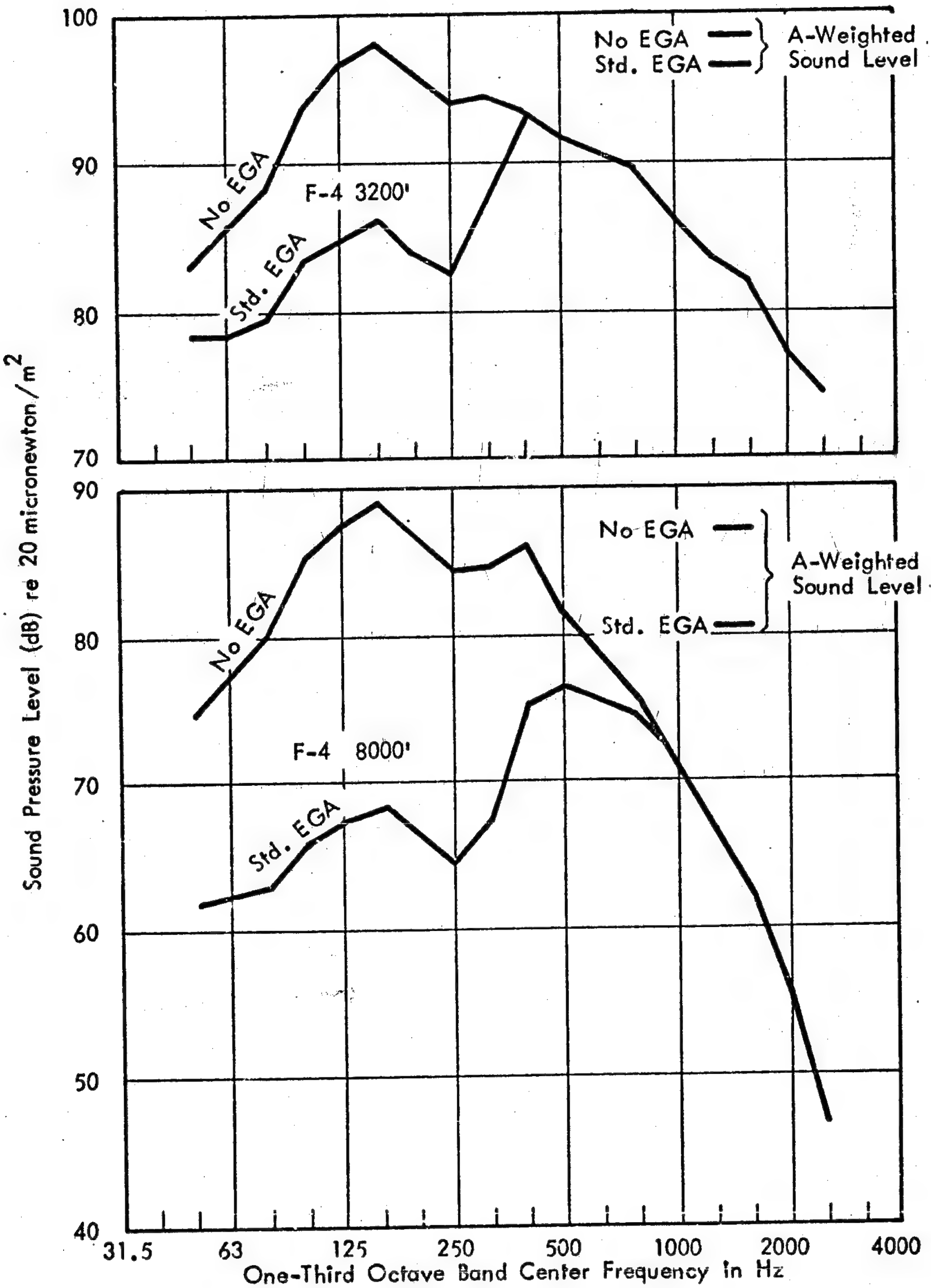

FIGURE 1. SPL FOR F-4 GROUND RUNUP AT 140°

(SINGLE ENGINE)

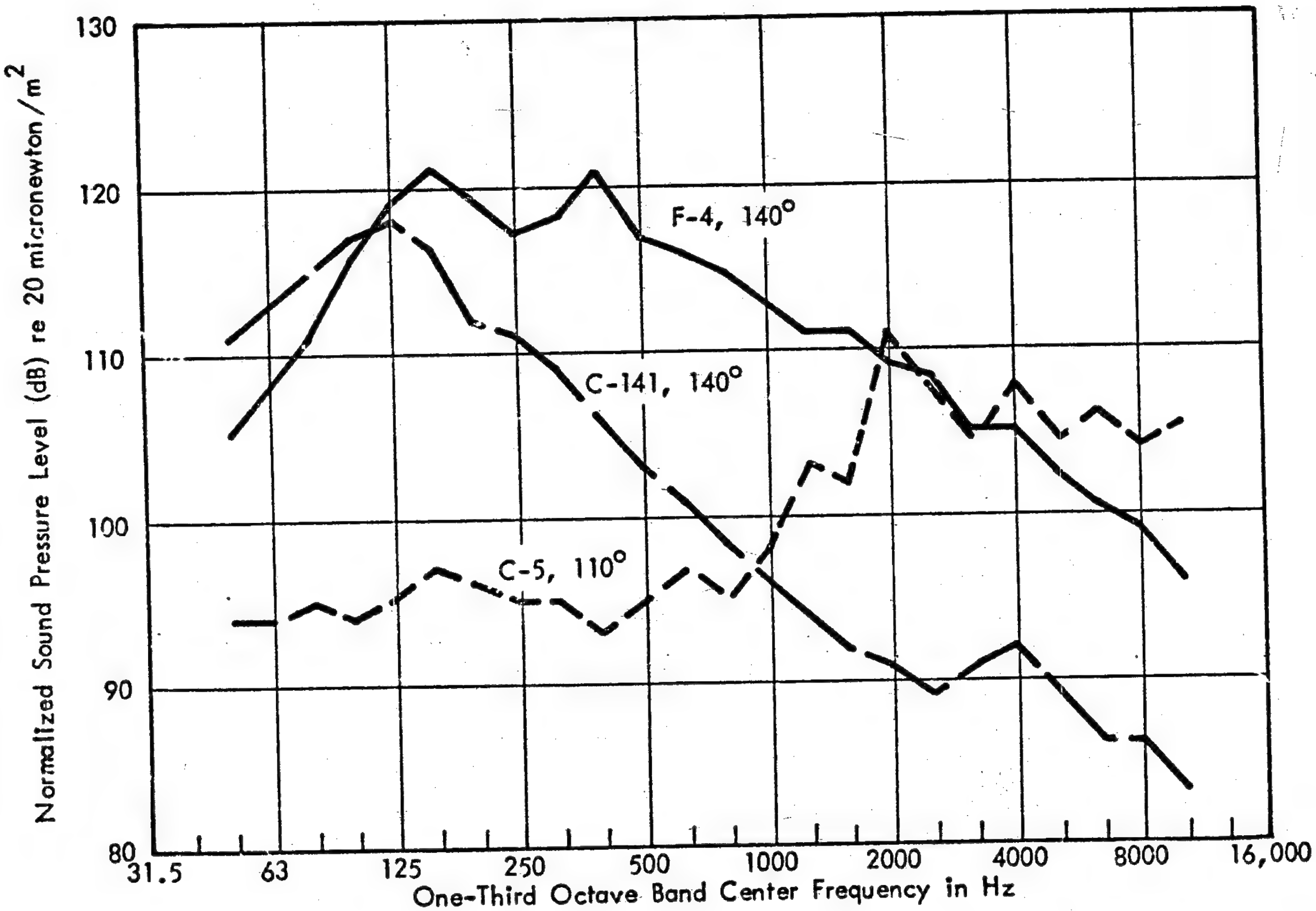

FIGURE 2. SPL SPECTRA FOR ANGLE-OF-MAXIMUM NOISE, 250 FEET
(SINGLE ENGINE)

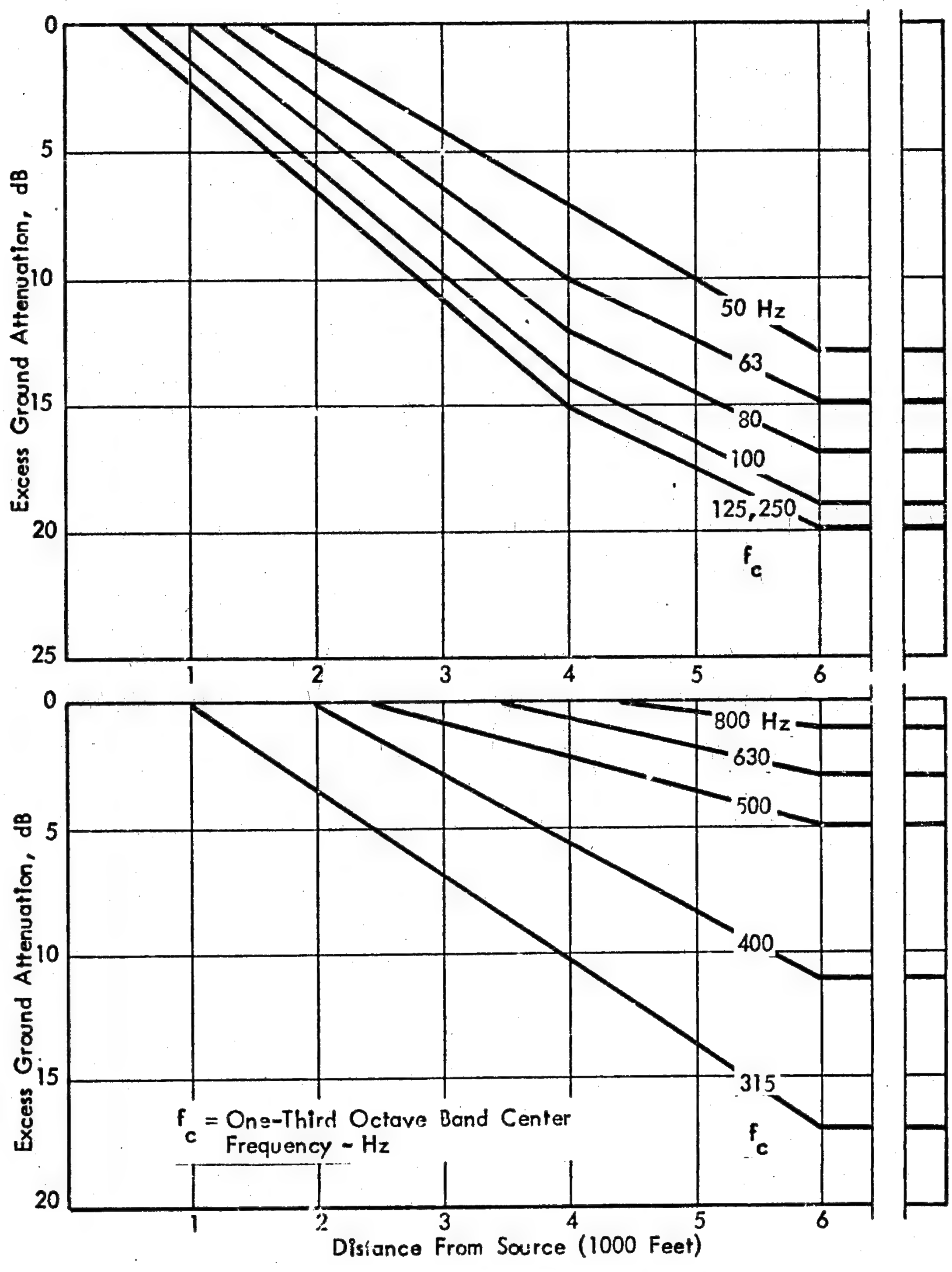

FIGURE 3. EXCESS GROUND ATTENUATION FOR GROUND-TO-GROUND SOUND PROPAGATION - STANDARD ALGORITHM

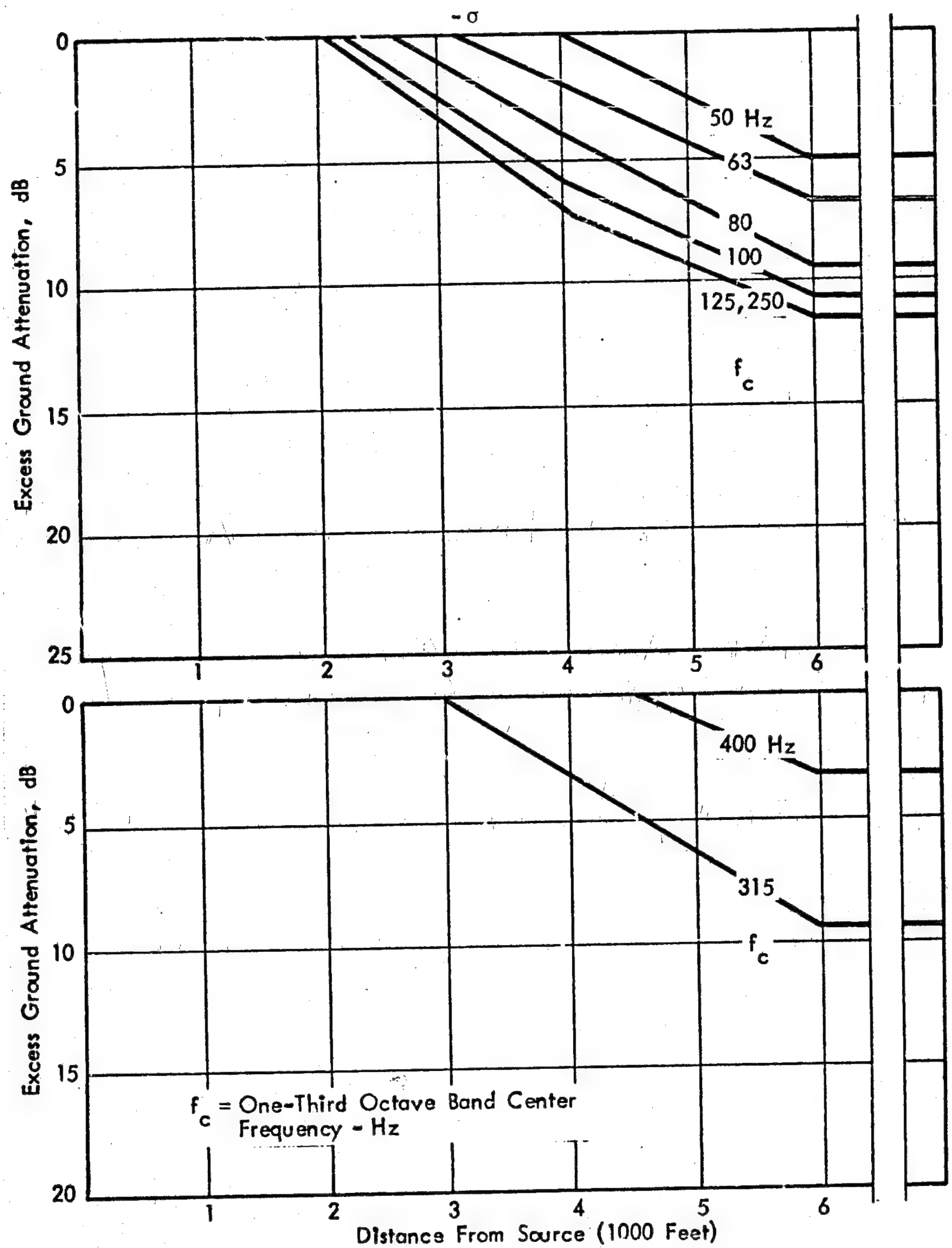

FIGURE 4. EXCESS GROUND ATTENUATION FOR GROUND-TO-GROUND SOUND PROPAGATION - MINUS SIGMA ALGORITHM

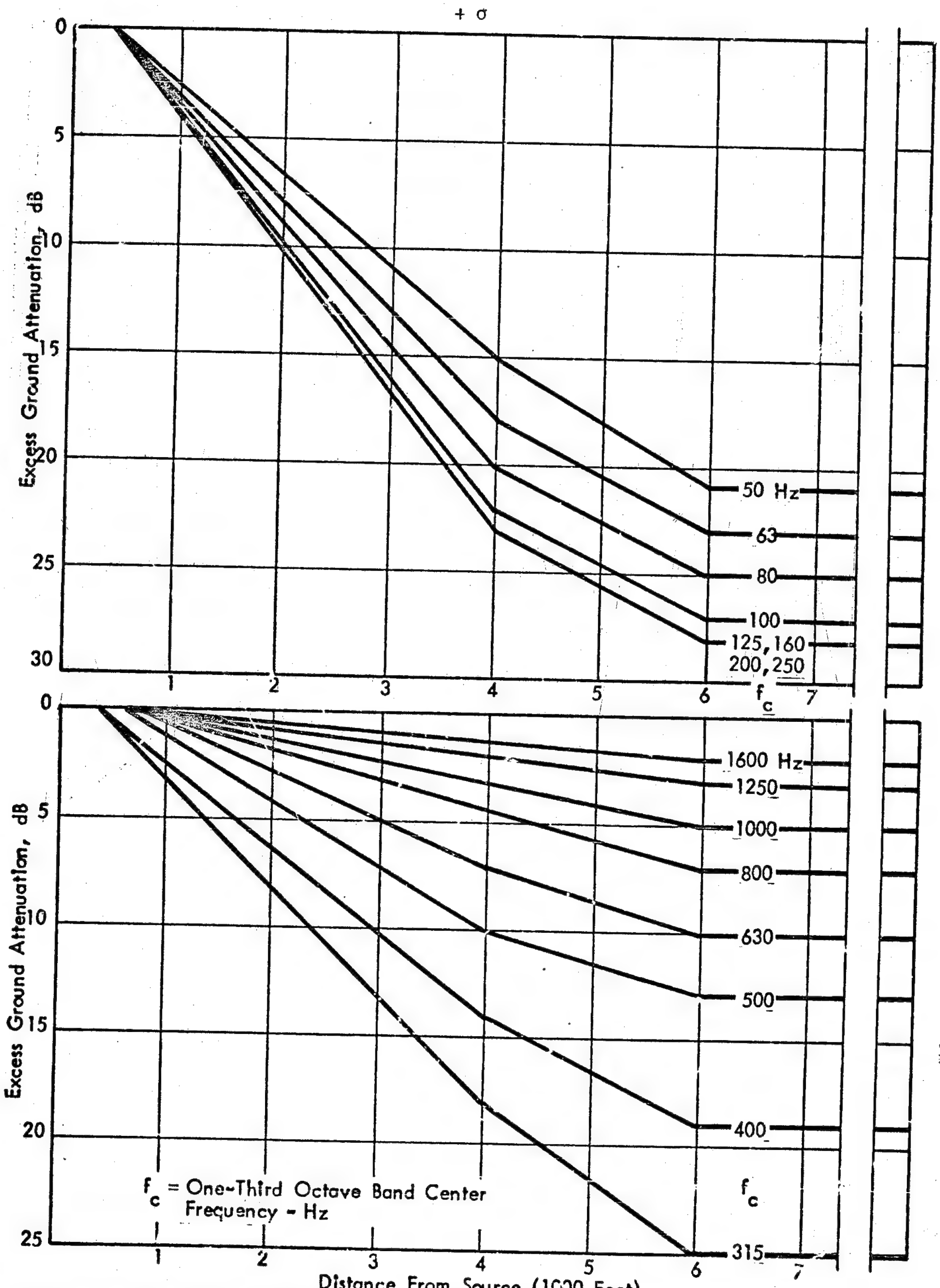

FIGURE 5. EXCESS GROUND ATTENUATION FOR GROUND-TO-GROUND SOUND PROPAGATION - PLUS SIGMA ALGORITHM

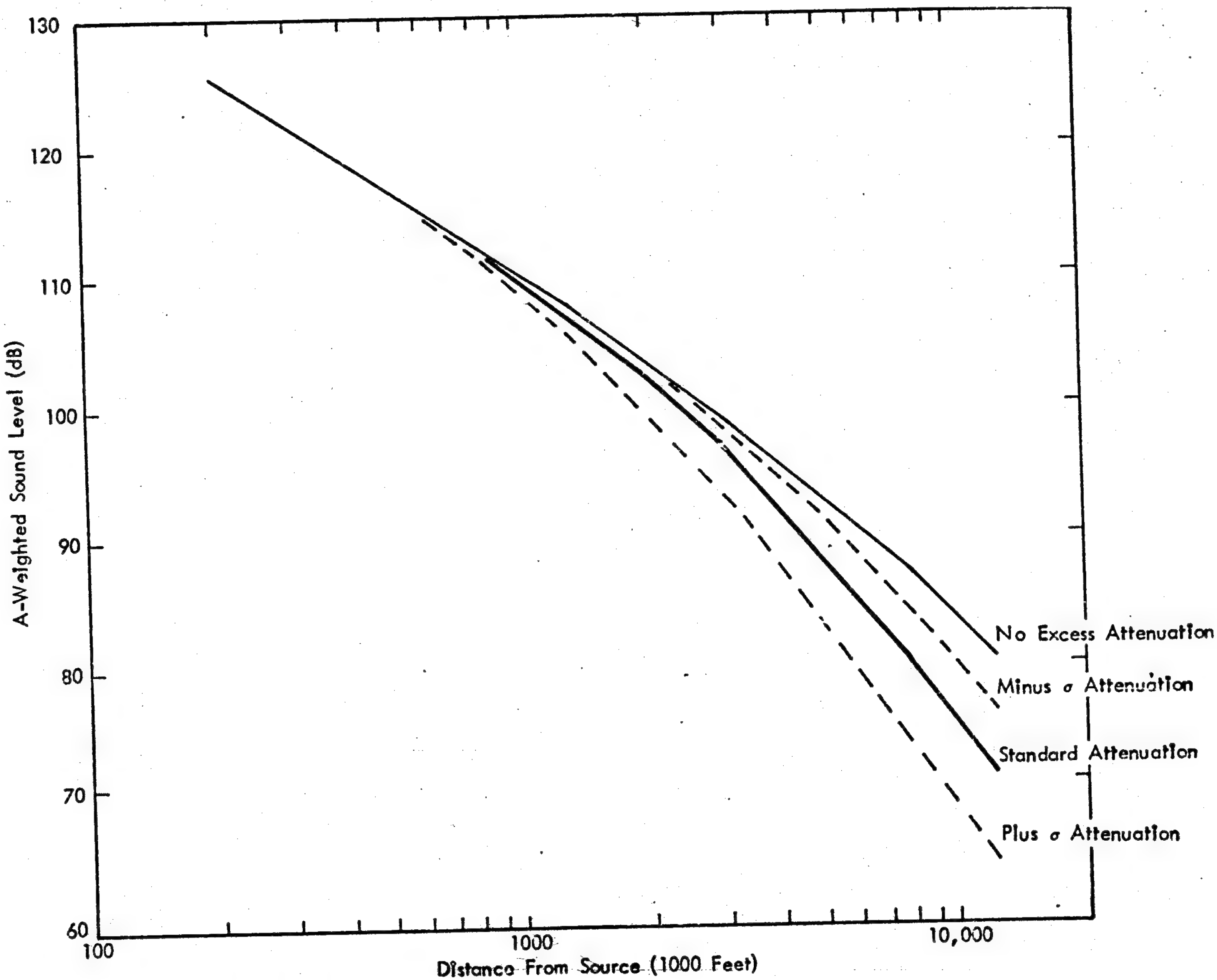

FIGURE 6. A-WEIGHTED SOUND LEVEL FROM F-4 AIRCRAFT (140° FROM ENGINE INLET, MILITARY POWER, SINGLE ENGINE)

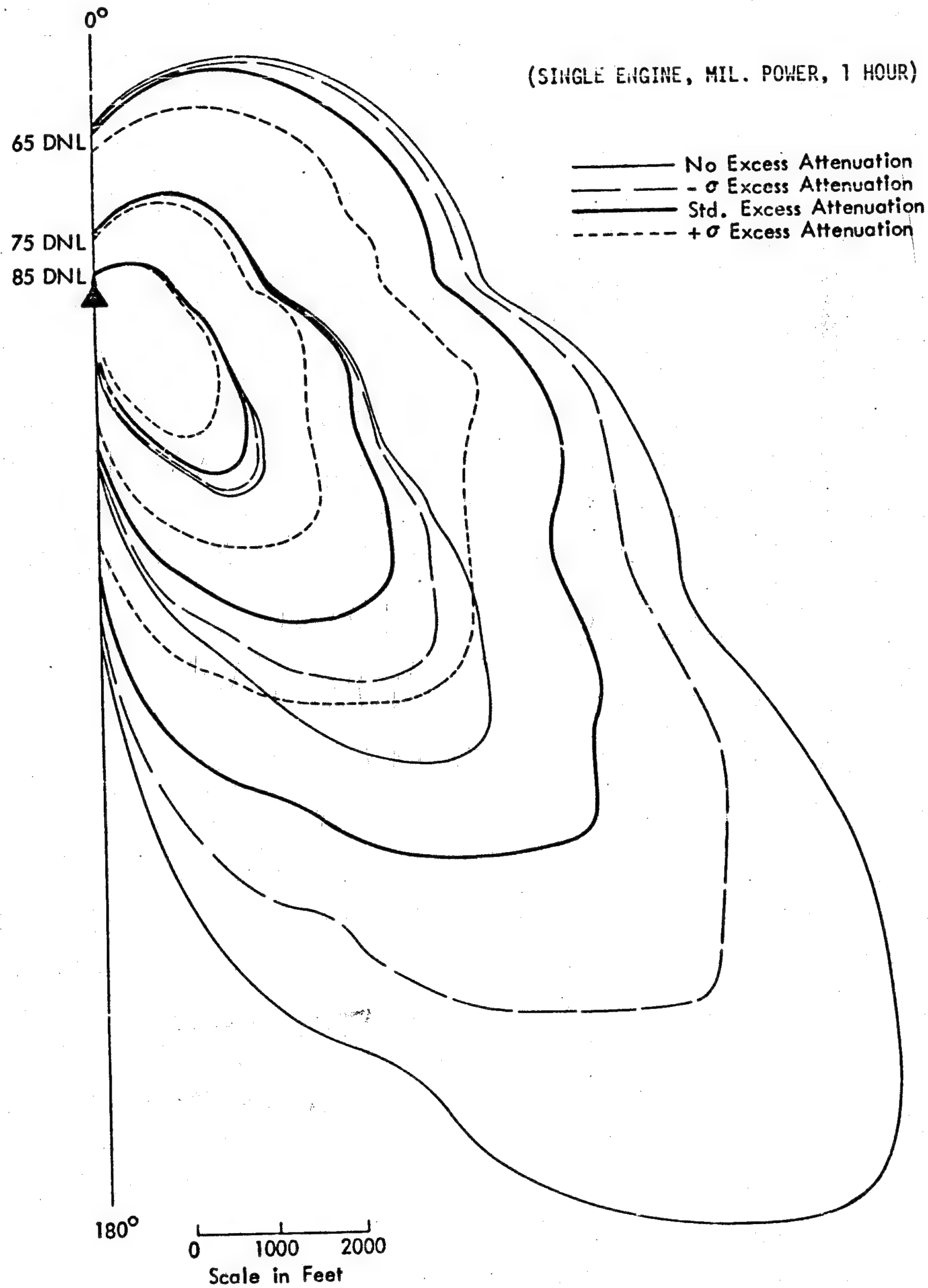

FIGURE 7. DNL CONTOUR FOR THE F-4 AIRCRAFT USING FOUR PROPAGATION ALGORITHMS

TABLE I

EXPOSURE AREAS FOR VARIOUS GROUND ATTENUATION ALGORITHMS (SQ. MILES)

A/C	DNL	No Excess Attenuation	$-\sigma$ Excess Attenuation	Std Excess Attenuation	$+\sigma$ Excess Attenuation	$\frac{\text{Std}-(-\sigma)}{\text{Std}}$	$\frac{\text{Std}-(+\sigma)}{\text{Std}}$
F-4	55	10.552	6.923	4.555	2.493	-0.52	0.45
	60	5.771	3.949	2.664	1.495	-0.48	0.44
	65	2.984	2.131	1.495	0.905	-0.43	0.39
	70	1.463	1.105	0.833	0.535	-0.33	0.36
	75	0.676	0.563	0.452	0.297	-0.25	0.34
	80	0.300	0.277	0.228	0.161	-0.21	0.29
	85	0.127	0.124	0.109	0.081	-0.14	0.26
C-141	55	4.246	1.918	1.328	0.879	-0.44	0.34
	60	1.952	1.019	0.773	0.533	-0.32	0.31
	65	0.850	0.551	0.419	0.301	-0.32	0.28
	70	0.355	0.286	0.218	0.172	-0.31	0.21
	75	0.145	0.140	0.108	0.092	-0.30	0.15
	80	0.059	0.059	0.050	0.045	-0.18	0.10
	85	0.023	0.023	0.021	0.020	-0.10	0.05
C-5	55	2.280	2.125	1.994	1.654	-0.07	0.17
	60	1.333	1.280	1.242	1.062	-0.03	0.14
	65	0.759	0.744	0.732	0.651	-0.02	0.11
	70	0.415	0.412	0.403	0.371	Insufficient Noise Level	
	75	0.222	0.222	0.218	0.206		
	80	0.111	0.111	0.111	0.107		
	85	0.053	0.053	0.052	0.050		

APPENDIX A

A-WEIGHTED LEVELS RESULTING FROM VARIOUS EXCESS GROUND ATTENUATION ALGORITHMS

ANGLE IN DEGREES Std.

DIST	0.0	20.0	90.0	110.0	120.0	130.0	140.0	150.0	160.0	180.0
200.0 FT	101.4	105.8	112.1	119.3	119.1	123.0	125.6	123.9	120.1	77.2
250.0 FT	99.3	103.7	110.0	117.1	117.0	120.9	123.5	121.8	118.1	75.2
315.0 FT	97.2	101.6	107.9	114.9	114.8	118.8	121.4	119.8	116.0	73.1
400.0 FT	95.0	99.4	105.7	112.7	112.7	116.7	119.3	117.6	113.9	71.0
500.0 FT	92.8	97.2	103.5	110.4	110.5	114.5	117.1	115.5	111.7	68.8
630.0 FT	90.6	95.0	101.2	108.1	108.2	112.3	114.9	113.2	109.5	66.5
800.0 FT	88.3	92.7	98.9	105.7	105.9	110.0	112.6	111.0	107.2	64.1
1000.0 FT	86.0	90.3	96.5	103.2	103.5	107.7	110.3	108.7	104.9	61.7
1250.0 FT	83.6	87.9	94.0	100.6	101.0	105.2	107.8	106.2	102.5	59.0
1600.0 FT	81.1	85.3	91.4	97.9	98.5	102.7	105.3	103.6	100.0	56.2
2000.0 FT	78.5	82.7	88.8	95.2	95.8	100.0	102.7	101.0	97.4	53.3
2500.0 FT	75.6	79.8	85.8	92.1	92.9	97.0	99.6	97.9	94.4	49.9
3150.0 FT	72.5	76.6	82.6	88.8	89.6	93.6	96.3	94.5	91.1	46.3
4000.0 FT	69.1	73.1	79.0	85.2	86.0	89.9	92.5	90.7	87.4	42.2
5000.0 FT	65.1	69.1	75.0	81.0	82.0	85.8	88.4	86.4	83.2	37.9
6300.0 FT	60.8	64.7	70.6	76.6	77.6	81.4	84.0	82.0	78.8	33.4
8000.0 FT	56.9	60.8	66.6	72.5	73.7	77.6	80.2	78.2	75.1	29.8
10000.0 FT	52.6	56.4	62.1	68.0	69.4	73.5	76.1	74.2	71.0	25.9
12500.0 FT	47.8	51.7	57.3	63.2	64.8	69.0	71.6	69.9	66.5	21.9
16000.0 FT	42.5	46.5	52.1	58.0	59.7	64.2	66.8	65.2	61.7	17.6
20000.0 FT	36.7	40.7	46.3	52.3	54.1	58.9	61.5	60.0	56.4	13.2
25000.0 FT	30.3	34.4	40.0	46.0	48.0	53.2	55.8	54.5	50.6	8.9

ANGLE IN DEGREES No Excess Attenuation

DIST	0.0	20.0	90.0	110.0	120.0	130.0	140.0	150.0	160.0	180.0
200.0 FT	101.4	105.8	112.1	119.3	119.1	123.0	125.6	123.9	120.1	77.2
250.0 FT	99.3	103.7	110.0	117.1	117.0	120.9	123.5	121.8	118.1	75.2
315.0 FT	97.2	101.6	107.9	114.9	114.8	118.8	121.4	119.8	116.0	73.1
400.0 FT	95.0	99.4	105.7	112.7	112.7	116.7	119.3	117.6	113.9	71.0
500.0 FT	92.9	97.2	103.5	110.4	110.5	114.5	117.1	115.5	111.7	69.0
630.0 FT	90.6	95.0	101.2	108.1	108.2	112.3	115.0	113.3	109.6	66.9
800.0 FT	88.4	92.7	98.9	105.7	105.9	110.1	112.8	111.2	107.4	64.7
1000.0 FT	86.1	90.4	96.5	103.2	103.6	107.9	110.5	108.9	105.1	62.6
1250.0 FT	83.7	88.0	94.1	100.7	101.2	105.5	108.2	106.6	102.8	60.4
1600.0 FT	81.3	85.6	91.6	98.1	98.7	103.2	105.9	104.3	100.5	58.2
2000.0 FT	78.8	83.0	89.0	95.3	96.2	100.7	103.4	101.9	98.1	55.9
2500.0 FT	76.2	80.4	86.2	92.5	93.5	98.2	101.0	99.5	95.6	53.7
3150.0 FT	73.4	77.6	83.4	89.5	90.8	95.6	98.4	96.9	93.0	51.3
4000.0 FT	70.6	74.7	80.4	86.5	87.9	93.0	95.7	94.3	90.3	48.9
5000.0 FT	67.6	71.7	77.3	83.3	85.0	90.2	92.9	91.6	87.5	46.4
6300.0 FT	64.4	68.5	74.0	79.9	81.8	87.2	90.0	88.7	84.6	43.9
8000.0 FT	61.0	65.1	70.5	76.4	78.5	84.2	87.0	85.7	81.5	41.3
10000.0 FT	57.4	61.6	66.8	72.7	75.0	80.9	83.8	82.6	78.2	38.5
12500.0 FT	53.5	57.7	62.9	68.7	71.3	77.5	80.3	79.2	74.7	35.7
16000.0 FT	49.4	53.7	58.8	64.5	67.3	73.8	76.7	75.6	71.0	32.7
20000.0 FT	45.2	49.4	54.4	60.1	63.1	69.9	72.9	71.8	67.0	29.6
25000.0 FT	40.6	44.8	49.8	55.3	58.7	65.8	68.8	67.7	62.8	26.2

F-4 Aircraft

ANGLE IN DEGREES -σ Attenuation

DIST	0.0	20.0	90.0	110.0	120.0	130.0	140.0	150.0	160.0	180.0
200.0 FT	101.4	105.8	112.1	119.3	119.1	123.0	125.6	123.9	120.1	77.2
250.0 FT	99.3	103.7	110.0	117.1	117.0	120.9	123.5	121.8	118.1	75.2
315.0 FT	97.2	101.6	107.9	114.9	114.8	118.8	121.4	119.8	116.0	73.1
400.0 FT	95.0	99.4	105.7	112.7	112.7	116.7	119.3	117.6	113.9	71.0
500.0 FT	92.9	97.2	103.5	110.4	110.5	114.5	117.1	115.5	111.7	69.0
630.0 FT	90.6	95.0	101.2	108.1	108.2	112.3	115.0	113.3	109.6	66.9
800.0 FT	88.4	92.7	98.9	105.7	105.9	110.1	112.8	111.2	107.4	64.7
1000.0 FT	86.1	90.4	96.5	103.2	103.6	107.9	110.5	108.9	105.1	62.6
1250.0 FT	83.7	88.0	94.1	100.7	101.2	105.5	108.2	106.6	102.8	60.4
1600.0 FT	81.3	85.6	91.6	98.1	98.7	103.2	105.9	104.3	100.5	58.2
2000.0 FT	78.8	83.0	89.0	95.3	96.2	100.7	103.4	101.9	98.1	55.9
2500.0 FT	76.1	80.3	86.2	92.5	93.5	98.1	100.8	99.3	95.4	53.0
3150.0 FT	73.3	77.4	83.2	89.4	90.6	95.2	97.9	96.4	92.6	49.6
4000.0 FT	70.2	74.3	80.1	86.2	87.4	92.1	94.8	93.2	89.5	45.8
5000.0 FT	66.8	70.9	76.6	82.7	84.0	88.6	91.3	89.7	86.0	41.9
6300.0 FT	63.1	67.1	72.9	78.9	80.3	84.7	87.4	85.8	82.2	37.7
8000.0 FT	59.4	63.5	69.2	75.1	76.7	81.3	84.0	82.4	78.8	34.6
10000.0 FT	55.5	59.5	65.2	71.1	72.8	77.6	80.3	78.8	75.1	31.2
12500.0 FT	51.1	55.3	60.8	66.8	68.6	73.7	76.3	74.9	71.1	27.7
16000.0 FT	46.4	50.6	56.1	62.1	64.1	69.3	72.0	70.7	66.8	24.1
20000.0 FT	41.2	45.5	51.0	56.9	59.0	64.6	67.3	66.0	62.0	20.3
25000.0 FT	35.6	39.9	45.3	51.2	53.5	59.4	62.2	60.9	56.7	16.4

ANGLE IN DEGREES +σ Attenuation

DIST	0.0	20.0	90.0	110.0	120.0	130.0	140.0	150.0	160.0	180.0
200.0 FT	101.4	105.8	112.1	119.3	119.1	123.0	125.6	123.9	120.1	77.2
250.0 FT	99.3	103.7	110.0	117.1	117.0	120.9	123.5	121.8	118.1	75.2
315.0 FT	97.2	101.6	107.9	114.9	114.8	118.8	121.4	119.8	116.0	73.1
400.0 FT	95.0	99.4	105.7	112.7	112.7	116.7	119.3	117.6	113.9	71.0
500.0 FT	92.8	97.1	103.4	110.4	110.4	114.4	117.0	115.3	111.6	68.6
630.0 FT	90.5	94.8	101.1	108.0	108.1	112.0	114.6	112.9	109.2	66.0
800.0 FT	88.1	92.4	98.7	105.5	105.6	109.5	112.1	110.4	106.7	63.3
1000.0 FT	85.4	89.7	96.0	102.8	102.9	106.7	109.3	107.6	104.0	60.3
1250.0 FT	82.6	86.9	93.2	100.0	100.1	103.8	106.4	104.6	101.1	57.2
1600.0 FT	79.6	83.9	90.2	96.9	97.0	100.7	103.3	101.5	98.0	53.8
2000.0 FT	76.4	80.7	87.0	93.6	93.7	97.3	99.9	98.0	94.6	50.1
2500.0 FT	72.9	77.2	83.5	90.0	90.2	93.7	96.2	94.3	91.0	46.1
3150.0 FT	69.1	73.3	79.6	86.1	86.2	89.7	92.2	90.2	87.0	41.8
4000.0 FT	64.8	69.0	75.3	81.7	81.9	85.2	87.8	85.7	82.6	37.1
5000.0 FT	60.2	64.3	70.7	77.0	77.2	80.5	83.1	81.1	77.9	32.4
6300.0 FT	55.3	59.3	65.6	71.8	72.2	75.6	78.2	76.1	73.0	27.4
8000.0 FT	51.1	55.0	61.1	67.2	67.8	71.4	74.0	72.0	68.9	23.4
10000.0 FT	46.5	50.4	56.3	62.2	63.2	67.0	69.6	67.6	64.5	19.2
12500.0 FT	41.5	45.3	51.0	56.9	58.2	62.2	64.8	62.9	59.7	14.8
16000.0 FT	35.9	39.8	45.4	51.3	52.8	57.1	59.7	57.9	54.5	10.2
20000.0 FT	29.8	33.7	39.3	45.2	46.9	51.5	54.1	52.6	49.0	5.6
25000.0 FT	23.1	27.1	32.7	38.6	40.5	45.6	48.2	46.8	43.0	1.1

F-4 Aircraft

ANGLE IN DEGREES Std.

DIST	0.0	30.0	50.0	60.0	70.0	80.0	110.0	130.0	150.0	180.0
200.0 FT	105.5	108.3	105.0	106.4	100.7	107.0	110.9	112.9	112.1	92.1
250.0 FT	103.2	106.0	102.7	104.1	98.4	104.7	108.6	110.8	110.1	90.1
315.0 FT	100.9	103.7	100.3	101.7	96.1	102.4	106.3	108.7	108.0	88.0
400.0 FT	98.5	101.2	97.9	99.2	93.6	99.9	103.8	106.6	105.9	85.9
500.0 FT	96.0	98.7	95.3	96.7	91.1	97.4	101.3	104.3	103.7	83.7
630.0 FT	93.5	96.0	92.7	94.0	88.5	94.8	98.7	101.9	101.4	81.4
800.0 FT	90.8	93.3	89.9	91.2	85.8	92.1	96.0	99.5	99.0	79.0
1000.0 FT	88.0	90.4	87.0	88.2	83.0	89.3	93.2	96.9	96.6	76.6
1250.0 FT	85.1	87.3	84.0	85.2	80.0	86.4	90.2	94.2	93.9	73.9
1600.0 FT	82.0	84.2	80.8	81.9	77.0	83.3	87.2	91.3	91.1	71.1
2000.0 FT	78.8	80.8	77.5	78.6	73.8	80.2	84.0	88.2	88.3	68.3
2500.0 FT	75.4	77.3	74.1	75.1	70.4	76.9	80.7	84.8	85.0	65.0
3150.0 FT	71.7	73.6	70.4	71.4	66.9	73.4	77.3	81.2	81.5	61.5
4000.0 FT	67.8	69.6	66.5	67.5	63.1	69.6	73.6	77.1	77.5	57.5
5000.0 FT	63.4	65.3	62.3	63.3	58.9	65.5	69.5	72.8	73.2	53.2
6300.0 FT	58.8	60.5	57.7	58.7	54.4	61.1	65.1	68.3	68.7	48.7
8000.0 FT	54.6	55.8	53.2	54.1	50.0	56.7	60.9	64.7	65.2	45.2
10000.0 FT	50.1	50.9	48.4	49.2	45.3	52.0	56.4	60.8	61.5	41.5
12500.0 FT	45.4	45.7	43.4	44.1	40.2	46.9	51.5	56.6	57.5	37.5
16000.0 FT	40.3	40.3	38.0	38.6	34.7	41.4	46.2	52.3	53.1	33.1
20000.0 FT	34.9	34.6	32.4	32.8	28.9	35.5	40.5	47.9	48.5	28.5
25000.0 FT	29.1	28.5	26.5	26.8	22.7	29.3	34.6	43.3	43.6	23.6

ANGLE IN DEGREES No Excess Attenuation

DIST	0.0	30.0	50.0	60.0	70.0	80.0	110.0	130.0	150.0	180.0
200.0 FT	105.5	108.3	105.0	106.4	100.7	107.0	110.9	112.9	112.1	92.1
250.0 FT	103.2	106.0	102.7	104.1	98.4	104.7	108.6	110.8	110.1	90.1
315.0 FT	100.9	103.7	100.3	101.7	96.1	102.4	106.3	108.7	108.0	88.0
400.0 FT	98.5	101.2	97.9	99.2	93.7	99.9	103.9	106.6	106.0	86.0
500.0 FT	96.0	98.7	95.3	96.7	91.2	97.4	101.3	104.5	103.9	83.9
630.0 FT	93.5	96.1	92.7	94.0	88.6	94.8	98.8	102.3	101.8	81.8
800.0 FT	90.8	93.3	90.0	91.2	85.9	92.2	96.1	100.2	99.7	79.7
1000.0 FT	88.1	90.4	87.1	88.3	83.1	89.4	93.4	98.0	97.6	77.6
1250.0 FT	85.2	87.4	84.2	85.3	80.2	86.5	90.5	95.8	95.4	75.4
1600.0 FT	82.3	84.3	81.1	82.1	77.2	83.6	87.7	93.6	93.2	73.2
2000.0 FT	79.3	81.1	78.0	78.9	74.2	80.6	84.8	91.3	91.0	71.0
2500.0 FT	76.2	77.8	74.8	75.7	71.1	77.5	81.9	89.0	88.7	68.7
3150.0 FT	73.2	74.4	71.7	72.3	67.9	74.4	78.9	86.6	86.4	66.4
4000.0 FT	70.0	71.0	68.4	69.0	64.7	71.2	76.0	84.2	84.0	64.0
5000.0 FT	66.9	67.5	65.2	65.6	61.4	68.0	73.0	81.8	81.5	61.5
6300.0 FT	63.8	64.0	61.9	62.2	58.0	64.6	69.9	79.2	79.0	59.0
8000.0 FT	60.5	60.4	58.6	58.7	54.6	61.2	66.7	76.6	76.3	56.3
10000.0 FT	57.2	56.8	55.3	55.2	51.1	57.8	63.5	73.8	73.5	53.5
12500.0 FT	53.8	53.2	51.9	51.6	47.6	54.2	60.2	70.9	70.5	50.5
16000.0 FT	50.2	49.5	48.4	48.0	44.0	50.6	56.7	67.8	67.4	47.4
20000.0 FT	46.4	45.7	44.9	44.4	40.4	46.9	53.1	64.6	64.1	44.1
25000.0 FT	42.5	41.7	41.1	40.5	36.6	43.1	49.4	61.1	60.6	40.6

C-141 Aircraft

ANGLE IN DEGREES -σ Attenuation

DIST	0.0	30.0	50.0	60.0	70.0	80.0	110.0	130.0	150.0	160.0
200.0 FT	105.5	108.3	105.0	106.4	100.7	107.0	110.9	112.9	112.1	92.1
250.0 FT	103.2	106.0	102.7	104.1	98.4	104.7	108.6	110.8	110.1	90.1
315.0 FT	100.9	103.7	100.3	101.7	96.1	102.4	106.3	108.7	108.0	88.0
400.0 FT	98.5	101.2	97.9	99.2	93.7	99.9	103.9	106.6	106.0	86.0
500.0 FT	96.0	98.7	95.3	96.7	91.2	97.4	101.3	104.5	103.9	83.9
630.0 FT	93.5	96.1	92.7	94.0	88.6	94.8	98.8	102.3	101.8	81.8
800.0 FT	90.8	93.3	90.0	91.2	85.9	92.2	96.1	100.2	99.7	79.7
1000.0 FT	88.1	90.4	87.1	88.3	83.1	89.4	93.4	98.0	97.6	77.6
1250.0 FT	85.2	87.4	84.2	85.3	80.2	86.5	90.5	95.8	95.4	75.4
1600.0 FT	82.3	84.3	81.1	82.1	77.2	83.6	87.7	93.6	93.2	73.2
2000.0 FT	79.3	81.1	78.0	78.9	74.2	80.6	84.8	91.3	91.0	71.0
2500.0 FT	76.1	77.7	74.7	75.5	70.9	77.4	81.6	88.2	88.0	68.0
3150.0 FT	72.7	74.2	71.2	72.0	67.5	74.0	78.3	84.6	84.7	64.7
4000.0 FT	69.1	70.4	67.5	68.3	63.9	70.4	74.7	80.7	80.9	60.9
5000.0 FT	65.3	66.4	63.6	64.4	60.1	66.7	71.0	76.7	77.1	57.1
6300.0 FT	61.3	62.2	59.5	60.2	56.1	62.7	67.0	72.5	73.2	53.2
8000.0 FT	57.6	58.0	55.5	56.2	52.0	58.7	63.3	69.3	70.0	50.0
10000.0 FT	53.7	53.7	51.3	51.9	47.8	54.5	59.2	66.0	66.6	46.6
12500.0 FT	49.5	49.2	47.0	47.4	43.3	50.0	54.9	62.4	63.0	43.0
16000.0 FT	45.1	44.6	42.4	42.7	38.6	45.2	50.4	58.7	59.2	39.2
20000.0 FT	40.3	39.7	37.7	37.8	33.7	40.2	45.6	54.8	55.1	35.1
25000.0 FT	35.1	34.4	32.7	32.6	28.5	35.0	40.7	50.8	50.8	30.8

ANGLE IN DEGREES +σ Attenuation

DIST	0.0	30.0	50.0	60.0	70.0	80.0	110.0	130.0	150.0	160.0
200.0 FT	105.5	108.3	105.0	106.4	100.7	107.0	110.9	112.9	112.1	92.1
250.0 FT	103.2	106.0	102.7	104.1	98.4	104.7	108.6	110.8	110.1	90.1
315.0 FT	100.9	103.7	100.3	101.7	96.1	102.4	106.3	108.7	108.0	88.0
400.0 FT	98.5	101.2	97.9	99.2	93.7	99.9	103.9	106.6	106.0	86.0
500.0 FT	96.0	98.7	95.3	96.6	91.1	97.4	101.3	104.1	103.5	83.5
630.0 FT	93.4	96.0	92.6	93.9	88.5	94.8	98.6	101.5	100.9	80.9
800.0 FT	90.6	93.2	89.8	91.1	85.7	92.0	95.8	98.7	98.2	78.2
1000.0 FT	87.7	90.2	86.8	88.1	82.8	89.1	92.8	95.7	95.2	75.2
1250.0 FT	84.5	87.0	83.6	84.9	79.7	86.0	89.7	92.5	92.0	72.0
1600.0 FT	81.2	83.6	80.2	81.4	76.3	82.7	86.3	89.0	88.6	68.6
2000.0 FT	77.6	80.0	76.6	77.8	72.8	79.1	82.7	85.3	84.8	64.8
2500.0 FT	73.7	76.2	72.7	73.9	69.0	75.3	78.9	81.2	80.7	60.7
3150.0 FT	69.5	72.0	68.5	69.7	64.9	71.3	74.8	76.9	76.3	56.3
4000.0 FT	64.8	67.5	64.0	65.1	60.4	66.8	70.3	72.2	71.5	51.5
5000.0 FT	59.8	62.5	59.0	60.2	55.5	61.9	65.5	67.5	66.9	46.9
6300.0 FT	54.4	57.0	53.7	54.8	50.2	56.7	60.3	62.5	62.0	42.0
8000.0 FT	49.4	51.7	48.6	49.7	45.3	51.9	55.7	58.4	58.4	38.4
10000.0 FT	44.3	46.0	43.2	44.2	40.0	46.7	50.7	54.1	54.4	34.4
12500.0 FT	39.0	40.0	37.5	38.4	34.3	41.1	45.4	49.6	50.2	30.2
16000.0 FT	33.5	33.8	31.5	32.3	28.3	35.1	39.6	45.0	45.7	25.7
20000.0 FT	27.7	27.6	25.4	25.9	22.0	28.7	33.5	40.3	40.9	20.9
25000.0 FT	21.5	21.1	19.1	19.5	15.5	22.1	27.2	35.6	35.9	15.9

C-141 Aircraft

ANGLE IN DEGREES Std.

DIST	0.0	20.0	40.0	70.0	90.0	100.0	110.0	120.0	150.0	180.0
200.0 FT	111.9	114.4	113.3	117.8	116.2	114.3	119.1	117.1	106.7	86.7
250.0 FT	109.7	112.2	111.1	115.6	114.0	112.0	116.8	114.8	104.5	84.5
315.0 FT	107.4	109.9	108.8	113.3	111.6	109.7	114.4	112.4	102.2	82.2
400.0 FT	105.1	107.6	106.4	111.0	109.2	107.3	111.9	110.0	99.8	79.8
500.0 FT	102.7	105.2	104.0	108.5	106.8	104.8	109.3	107.5	97.4	77.4
630.0 FT	100.2	102.8	101.5	106.0	104.2	102.2	106.7	104.9	94.9	74.9
800.0 FT	97.7	100.2	98.9	103.5	101.5	99.6	104.0	102.3	92.2	72.2
1000.0 FT	95.0	97.5	96.2	100.8	98.7	96.8	101.1	99.5	89.5	69.5
1250.0 FT	92.2	94.8	93.4	97.9	95.8	93.9	98.1	96.5	86.5	66.5
1600.0 FT	89.3	91.8	90.4	94.9	92.7	90.9	95.0	93.5	83.4	63.4
2000.0 FT	86.2	88.7	87.2	91.7	89.4	87.7	91.6	90.2	80.1	60.1
2500.0 FT	82.9	85.4	83.8	88.3	85.9	84.3	88.1	86.6	76.6	56.6
3150.0 FT	79.3	81.8	80.2	84.7	82.1	80.7	84.2	82.8	72.7	52.7
4000.0 FT	75.5	77.9	76.2	80.7	78.0	76.7	80.0	78.6	68.5	48.5
5000.0 FT	71.2	73.6	71.9	76.3	73.6	72.4	75.3	73.9	63.8	43.8
6300.0 FT	66.5	68.8	67.1	71.4	68.7	67.7	70.2	68.8	58.8	38.8
8000.0 FT	61.7	63.7	61.9	66.3	63.6	62.7	64.9	63.5	53.7	33.7
10000.0 FT	56.5	58.0	56.2	60.9	58.1	57.3	59.2	57.9	48.6	28.6
12500.0 FT	50.9	51.7	50.0	55.0	52.1	51.5	53.2	52.2	43.3	23.3
16000.0 FT	44.9	44.9	43.3	48.7	45.8	45.2	47.0	46.3	37.8	17.8
20000.0 FT	38.5	37.8	36.3	42.0	39.2	38.7	40.6	40.2	32.3	12.3
25000.0 FT	31.8	30.5	29.3	35.0	32.3	32.0	34.0	33.9	26.8	6.8

ANGLE IN DEGREES No Excess Attenuation

DIST	0.0	20.0	40.0	70.0	90.0	100.0	110.0	120.0	150.0	180.0
200.0 FT	111.9	114.4	113.3	117.8	116.2	114.3	119.1	117.1	106.7	86.7
250.0 FT	109.7	112.2	111.1	115.6	114.0	112.0	116.8	114.8	104.5	84.5
315.0 FT	107.4	109.9	108.8	113.3	111.6	109.7	114.4	112.4	102.2	82.2
400.0 FT	105.1	107.6	106.4	111.0	109.2	107.3	111.9	110.0	99.8	79.8
500.0 FT	102.7	105.2	104.0	108.5	106.8	104.8	109.3	107.5	97.4	77.4
630.0 FT	100.2	102.8	101.5	106.1	104.2	102.2	106.7	104.9	94.9	74.9
800.0 FT	97.7	100.2	98.9	103.5	101.5	99.6	104.0	102.3	92.3	72.3
1000.0 FT	95.0	97.6	96.2	100.8	98.7	96.8	101.1	99.5	89.5	69.5
1250.0 FT	92.3	94.8	93.4	97.9	95.8	94.0	98.1	96.6	86.7	66.7
1600.0 FT	89.3	91.8	90.4	94.9	92.7	91.0	95.0	93.5	83.6	63.6
2000.0 FT	86.3	88.7	87.3	91.8	89.5	87.8	91.7	90.3	80.4	60.4
2500.0 FT	83.1	85.4	83.9	88.4	86.0	84.5	88.2	86.8	77.1	57.1
3150.0 FT	79.6	81.9	80.4	84.8	82.4	81.0	84.4	83.1	73.5	53.5
4000.0 FT	76.0	78.1	76.5	81.0	78.4	77.3	80.3	79.1	69.9	49.9
5000.0 FT	72.2	74.0	72.5	76.8	74.3	73.4	76.0	74.9	66.2	46.2
6300.0 FT	68.2	69.6	68.1	72.5	70.0	69.3	71.5	70.6	62.5	42.5
8000.0 FT	64.0	65.0	63.6	67.9	65.6	65.1	66.9	66.3	59.0	39.0
10000.0 FT	59.8	60.1	58.9	63.2	61.1	60.9	62.3	62.2	55.6	35.6
12500.0 FT	55.6	55.3	54.4	58.5	56.8	56.8	58.0	58.2	52.3	32.3
16000.0 FT	51.4	50.8	50.1	53.8	52.6	52.7	53.7	54.4	49.0	29.0
20000.0 FT	47.3	46.5	46.1	49.1	48.4	48.8	49.6	50.6	45.6	25.6
25000.0 FT	43.1	42.3	42.1	44.5	44.3	44.8	45.4	46.7	42.1	22.1

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ANGLE IN DEGREES -σ Attenuation

DIST	0.0	20.0	40.0	70.0	90.0	100.0	110.0	120.0	150.0	180.0
200.0 FT	111.9	114.4	113.3	117.8	116.2	114.3	119.1	117.1	106.7	86.7
250.0 FT	109.7	112.2	111.1	115.6	114.0	112.0	116.8	114.8	104.5	84.5
315.0 FT	107.4	109.9	108.8	113.3	111.6	109.7	114.4	112.4	102.2	82.2
400.0 FT	105.1	107.6	106.4	111.0	109.2	107.3	111.9	110.0	99.8	79.8
500.0 FT	102.7	105.2	104.0	108.5	106.8	104.8	109.3	107.5	97.4	77.4
630.0 FT	100.2	102.8	101.5	106.1	104.2	102.2	106.7	104.9	94.9	74.9
800.0 FT	97.7	100.2	98.9	103.5	101.5	99.6	104.0	102.3	92.3	72.3
1000.0 FT	95.0	97.6	96.2	100.8	98.7	96.8	101.1	99.5	89.5	69.5
1250.0 FT	92.3	94.8	93.4	97.9	95.8	94.0	98.1	96.6	86.7	66.7
1600.0 FT	89.3	91.8	90.4	94.9	92.7	91.0	95.0	93.5	83.6	63.6
2000.0 FT	86.3	88.7	87.3	91.8	89.5	87.8	91.7	90.3	80.4	60.4
2500.0 FT	83.0	85.4	83.9	88.4	86.0	84.5	88.1	86.7	76.9	56.9
3150.0 FT	79.5	81.9	80.3	84.8	82.3	80.9	84.3	83.0	73.2	53.2
4000.0 FT	75.8	78.0	76.4	80.9	78.3	77.0	80.2	78.8	69.1	49.1
5000.0 FT	71.8	73.8	72.1	76.6	73.9	72.9	75.7	74.4	64.8	44.8
6300.0 FT	67.4	69.2	67.5	72.1	69.3	68.4	70.9	69.6	60.2	40.2
8000.0 FT	62.9	64.2	62.5	67.3	54.5	63.7	65.9	64.8	55.7	35.7
10000.0 FT	58.2	58.9	57.2	62.2	59.4	58.8	60.7	59.8	51.3	31.3
12500.0 FT	53.2	53.1	51.6	56.9	54.1	53.6	55.5	54.9	46.9	26.9
16000.0 FT	47.9	47.2	45.9	51.4	48.7	48.3	50.2	49.8	42.4	22.4
20000.0 FT	42.4	41.2	40.2	45.6	43.1	42.8	44.7	44.6	37.9	17.9
25000.0 FT	36.7	35.3	34.6	39.5	37.4	37.3	39.0	39.3	33.2	13.2

ANGLE IN DEGREES +σ Attenuation

DIST	0.0	20.0	40.0	70.0	90.0	100.0	110.0	120.0	150.0	180.0
200.0 FT	111.9	114.4	113.3	117.8	116.2	114.3	119.1	117.1	106.7	86.7
250.0 FT	109.7	112.2	111.1	115.6	114.0	112.0	116.8	114.8	104.5	84.5
315.0 FT	107.4	109.9	108.8	113.3	111.6	109.7	114.4	112.4	102.2	82.2
400.0 FT	105.1	107.6	106.4	111.0	109.2	107.3	111.9	110.0	99.8	79.8
500.0 FT	102.7	105.2	104.0	108.5	106.8	104.8	109.3	107.5	97.4	77.4
630.0 FT	100.2	102.8	101.5	106.0	104.2	102.2	106.7	104.9	94.8	74.8
800.0 FT	97.6	100.2	98.9	103.4	101.5	99.6	103.9	102.2	92.2	72.2
1000.0 FT	94.9	97.5	96.1	100.7	98.7	96.7	101.1	99.4	89.3	69.3
1250.0 FT	92.0	94.6	93.2	97.8	95.7	93.7	98.0	96.4	86.3	66.3
1600.0 FT	88.9	91.5	90.1	94.7	92.5	90.6	94.8	93.3	83.1	63.1
2000.0 FT	85.6	88.2	86.7	91.3	89.0	87.2	91.3	89.8	79.6	59.6
2500.0 FT	82.0	84.6	83.1	87.7	85.3	83.5	87.6	86.1	75.9	55.9
3150.0 FT	78.0	80.7	79.2	83.7	81.2	79.6	83.5	82.1	71.7	51.7
4000.0 FT	73.6	76.4	74.8	79.3	76.7	75.1	79.0	77.5	67.1	47.1
5000.0 FT	68.8	71.5	69.9	74.3	71.7	70.2	73.9	72.5	61.9	41.9
6300.0 FT	63.4	66.1	64.5	68.8	66.1	64.8	68.2	66.7	56.2	36.2
8000.0 FT	57.9	60.6	58.9	63.1	60.4	59.3	62.2	60.6	50.3	30.3
10000.0 FT	52.1	54.5	52.7	57.0	54.2	53.3	55.6	54.1	44.1	24.1
12500.0 FT	45.8	47.7	45.9	50.3	47.5	46.8	48.6	47.2	37.8	17.8
16000.0 FT	39.1	40.2	38.4	43.3	40.5	39.8	41.5	40.4	31.5	11.5
20000.0 FT	32.1	32.2	30.5	35.9	33.0	32.5	34.3	33.5	25.3	5.3
25000.0 FT	24.8	23.9	22.5	28.2	25.4	25.0	26.9	26.7	19.3	-.7

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